



Solar System Exploration @ 50





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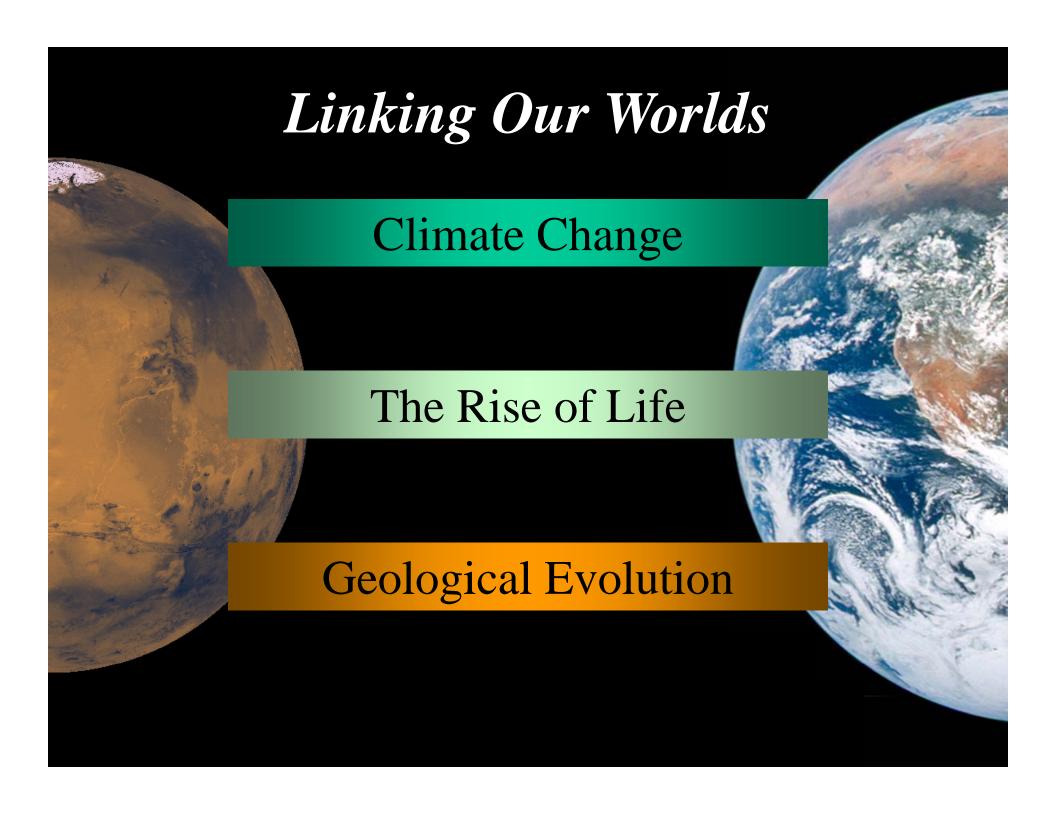
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California Institute of Technology

Mars Exploration



- Persistent themes
- Background
 - Lowellian View
- The First Wave of Exploring Mars from Space
 - Strategy: Fly-by Recon => Orbital Recon => Land
 - U. S. Mariners and Vikings
 - Soviet Mars and Zond s/c
- The Second Wave of Exploring Mars from Space:
 - The Modern Mars Exploration Program
 - Strategy: Orbiter-Lander Synergy & Ground Mobility
- Our view(s) of Mars Today
- Next Steps in Mars Exploration



Mars as an older Earth - P. Lowell



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The view of Mars at the beginning of the 20th Century

Both Earth and Mars had:

- Seasons and Seasonal Change
 - Polar caps that come and go seasonally
 - Changes in color, also with season: the "Wave of Darkening"
- Atmospheres
 - Mars less air than Earth, but enough for life (~10% of Earth's)
- Active Water Cycles: clouds, ice caps
- Similar length of day: Moderate diurnal variations
- Same evolutionary path--Mars was just older
 - Losing atmospheric and surface water over time
 - A heavily eroded desert planet (no mountains)
- Abodes of Life
 - Intelligent life: The canals were a vast engineering scheme to distribute the water from the poles to elsewhere on the planet



Mars at the Start of the Space Age



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Earth-based

- •Many doubts about the classical arguments for Martian life
 - Color of the dark areas: not green
 - Seasonal changes in visual albedo: winds removing dust
 - Ability of dark areas to re-emerge after dust storms: winds again?
 - Existence of canals discredited with improving image resolution
 - Early doubts about whether Mars was in the "habitability zone"

•Atmospheres

- Mars atmosphere much thinner than Earth's
 - CO₂ measurement => < 10% of Earth's total atmospheric column
 - Yes, there was some water vapor

Mariner 4 successfully launches in 1964 and initiates the age of Mars exploration by spacecraft

Mars: First Wave of the Space Age



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1964 - 1981 (US Program)

Mariner 4, 6-7: Mars as the Moon

- •Heavily cratered surface => Mars as the Moon
- •Total atmospheric pressure ~ 4 mbars (< 1% Earth), almost all CO₂

Mariner 9: A Dynamic Planet once again

- •Planetary Dichotomy: Heavily cratered highlands in the south and less cratered lowlands in the north
- •Massive volcanoes, giant rifts, vast channels, and valley networks
- Planet-wide dust storms

Viking: Life?

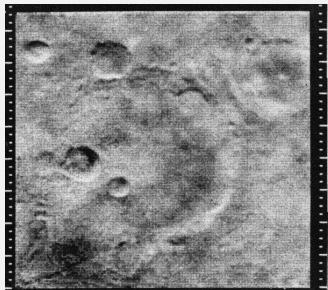
- •Experiments predicated on the assumption that if life exists somewhere on Mars, it will exist everywhere
- •Orbiters revealed an annual atmospheric water cycle
- •No confirmed biological activity; no organics in the soil



Early Views from Space

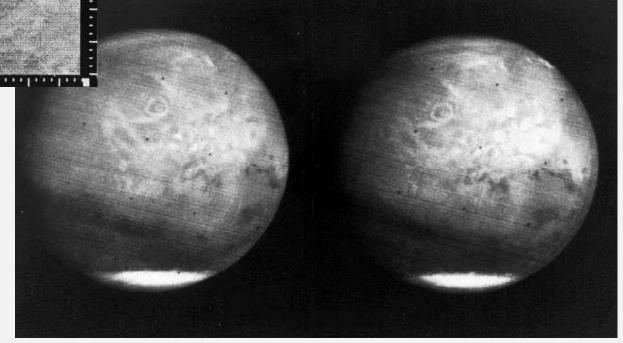


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1965: Mariner 4 photos reveal a moonscape 1969: Mariner 6 & 7 photos continue to puzzle

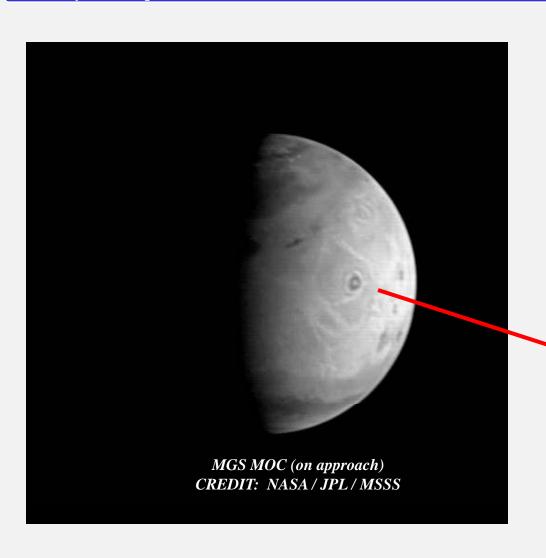
Mariners 4 & 7
CREDIT: NASA/JPL



Now We Know!



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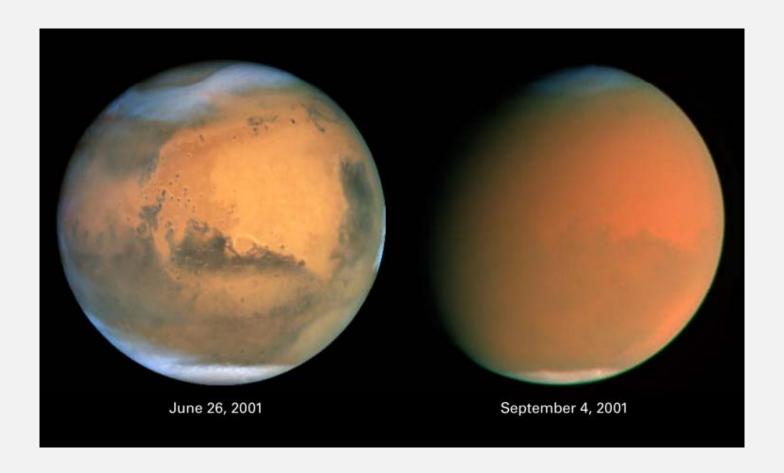


Olympus Mons

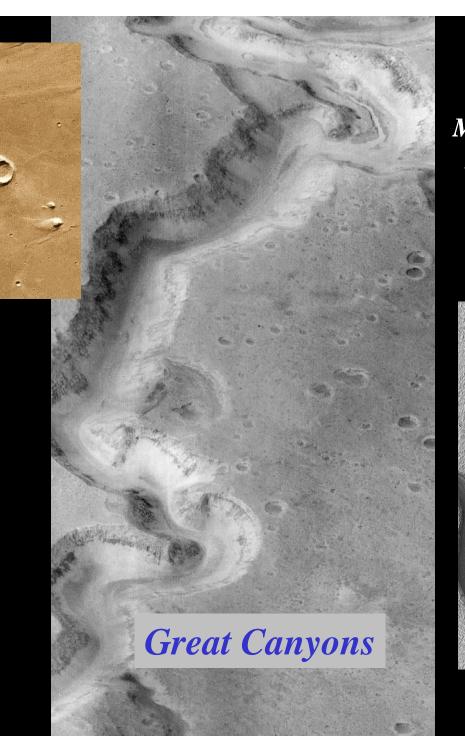


HST View in 2001





CREDIT: NASA/STScI/AURA/J. Bell & M. Wolff

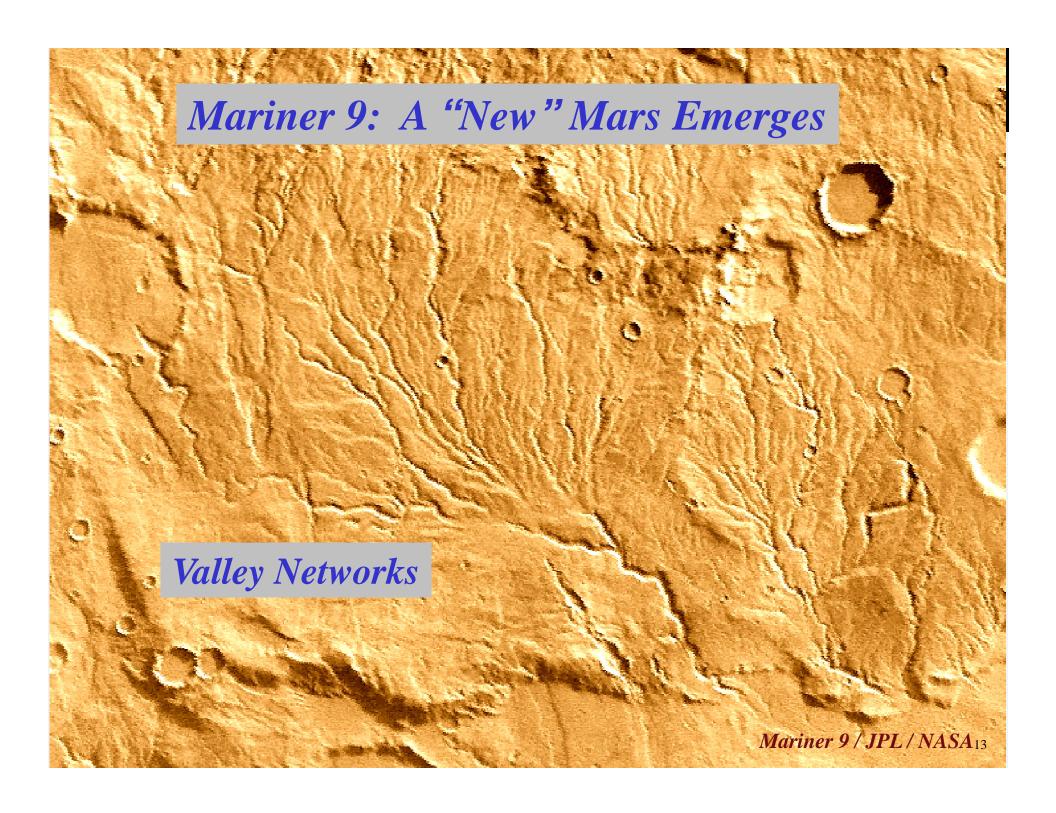


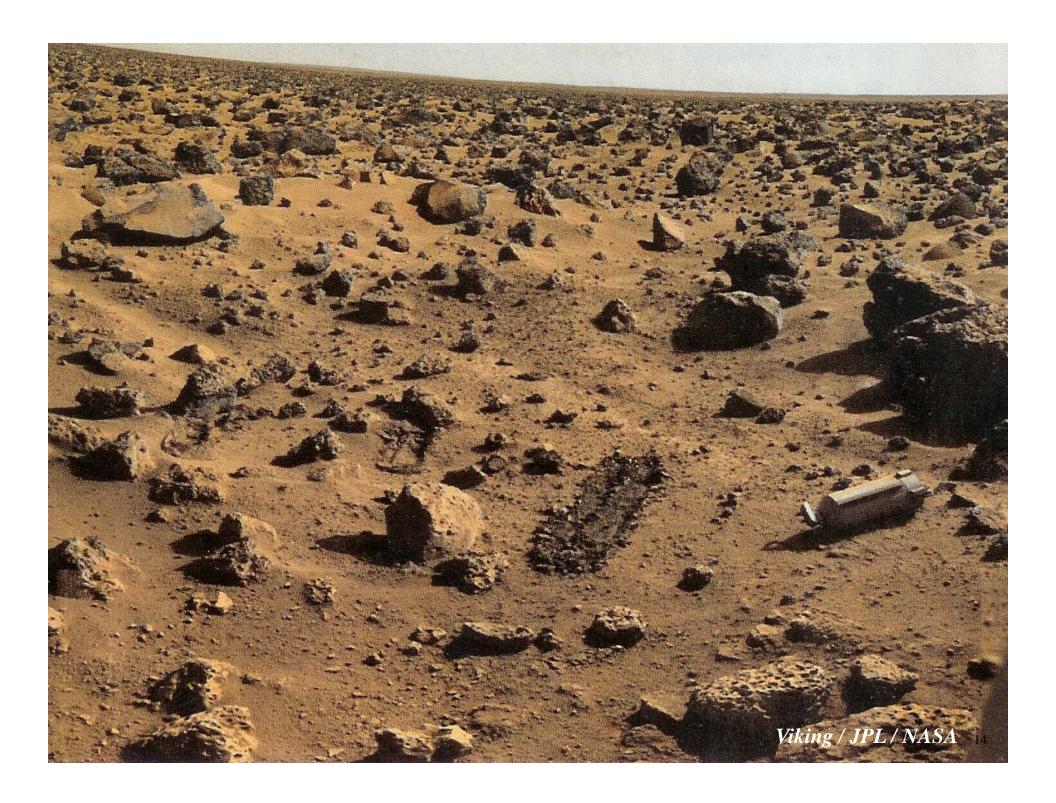
Mariner 9

CREDIT: NASA/JPL

Mars Global Surveyor Images Courtesy of MSSS/JPL/NASA







Mars: 2nd Wave of the Space Age



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1992 - 2012 +

Mars Pathfinder and Mars Global Surveyor

- •Successful Orbiter and Lander (with rover)!
- •Global mapping of the Planet; site finding for MER

Mars Odyssey, Mars Express, Mars Reconnaissance Orbiter

- •High spatial resolution imaging and monitoring; site finding for MSL
- •Shallow ground ice in mid-to-high latitudes
- •Diverse surface mineralogy points to diverse, potentially habitable ancient environments

Mars Exploration Rovers: Spirit & Opportunity

•Evidence for past water activity on the ground and in the near-surface

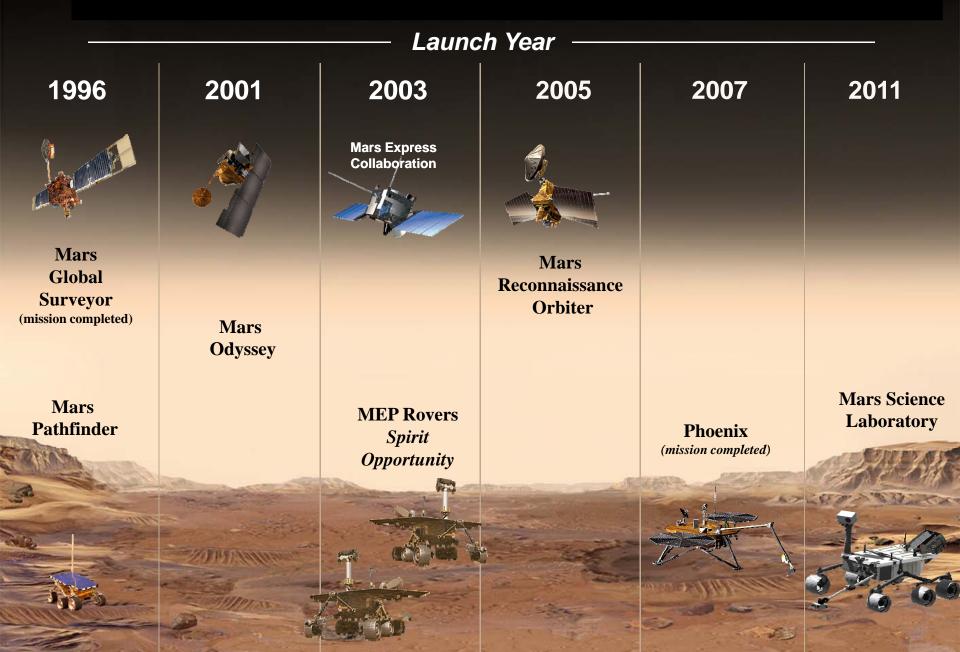
Phoenix

•Excavation of near-surface ice and salts at high latitudes

Mars Science Laboratory - Curiosity

•Characterizing a potentially habitable site

This Decade Mars Exploration



Mars Pathfinder & Sojourner Rover



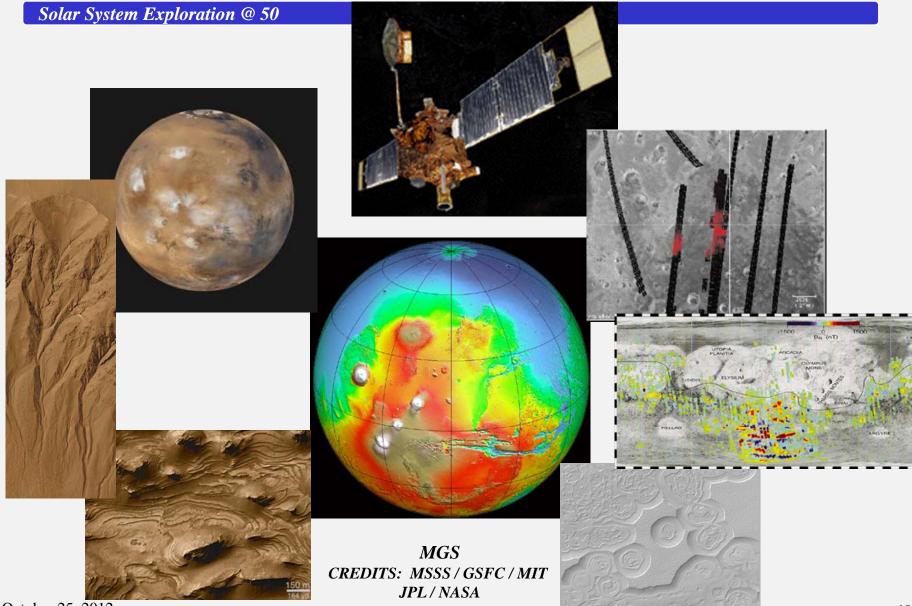
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Mars Global Surveyor:

A Science Catalyst for the Mars Exploration Program





How to Raise Dust on Mars



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MGS Mars Orbiter Camera (MOC)

Dust Devil Tracks

Local Dust Storm at South Pole Cap Edge





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Opportunity: Eagle Crater

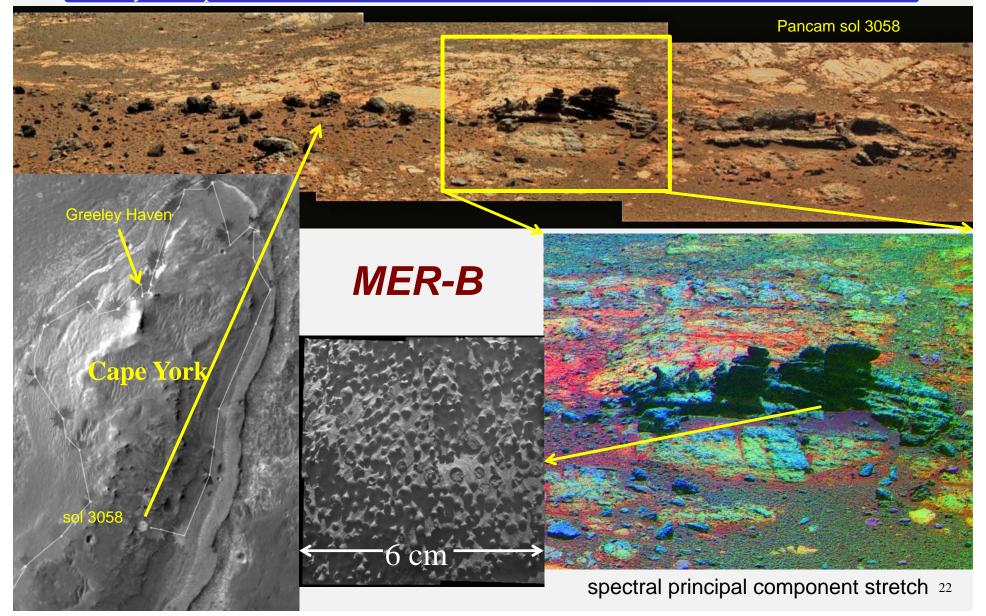


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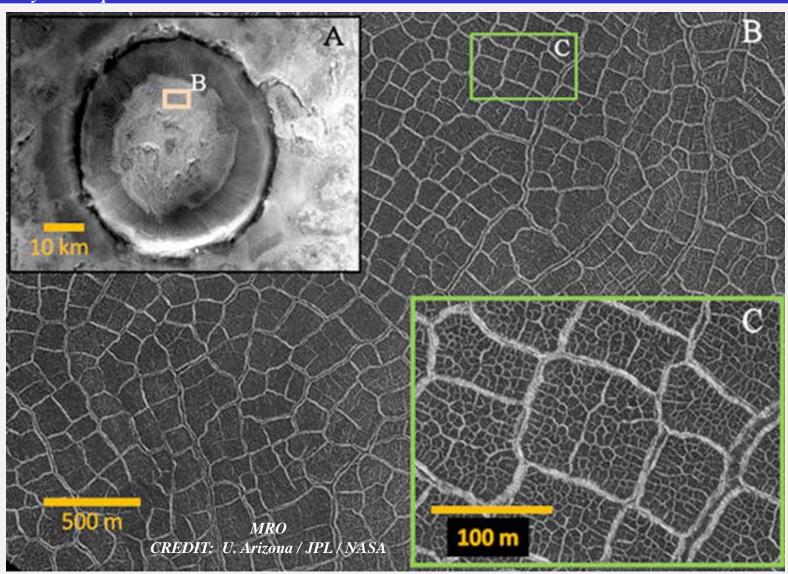
Opportunity at Endeavour Crater

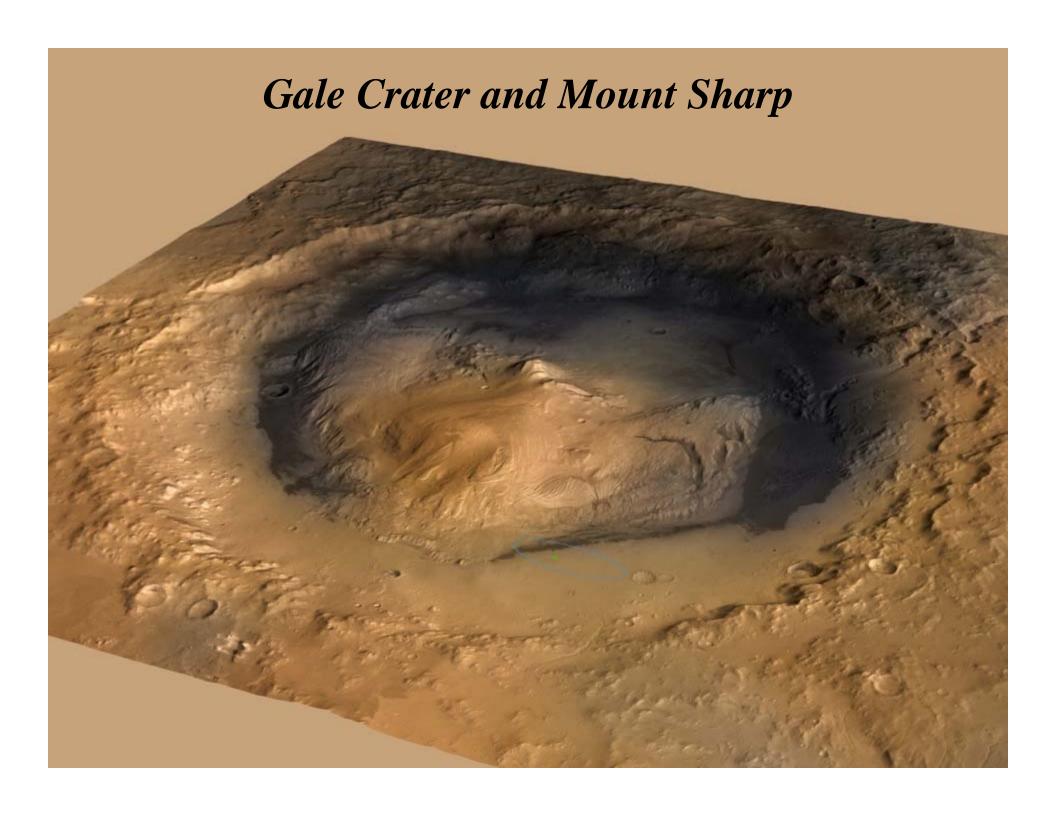




Mars Patterned Ground







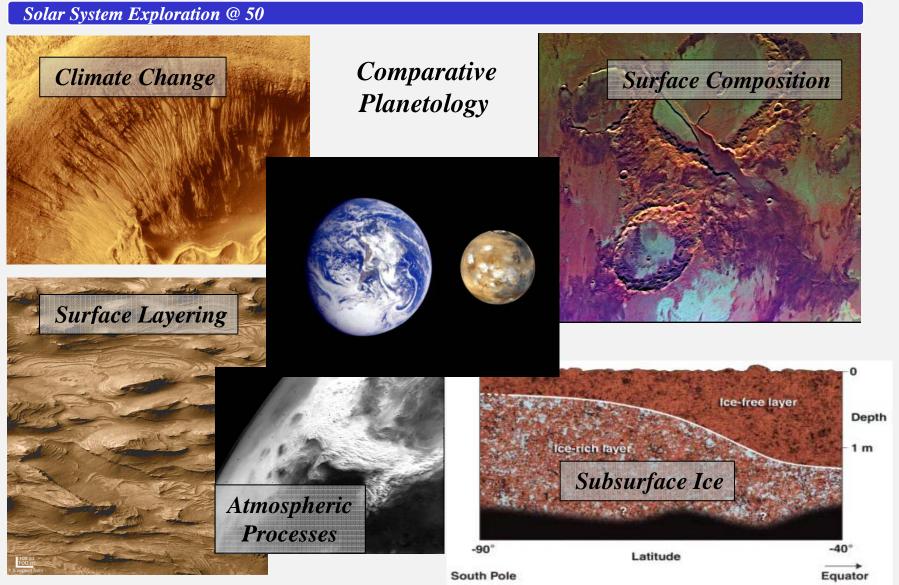
Foothills of Mt. Sharp





Mars: A Complex Planet

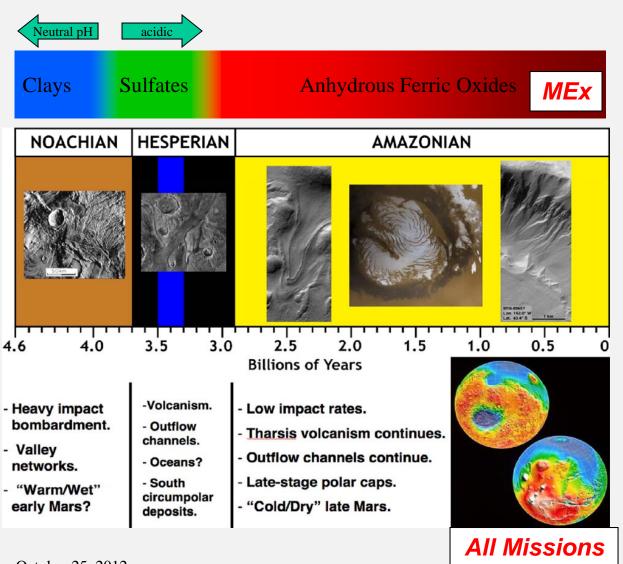




Mars Planetary Evolution



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☐ Hydrous Mineralogy Changed Over Time

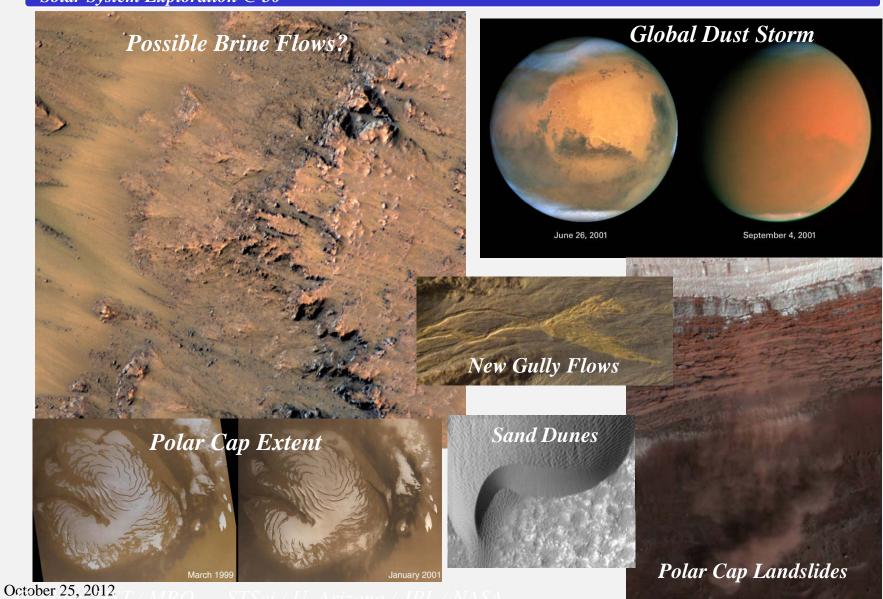
- Phyllosilicate minerals (smectite clay, chlorite, kaolinite...) formed early
- Evaporates dominated by sulfate formed later with opal/hydrated silica
 - Few hydrated mineral deposits since

□ Evolution of Aqueous, Fluvial and Glacial, Morphology with Time

- Valley networks, lake systems
 - Gullies
- Viscous flow, glaciers, latitude dependant mantle

Mars: A Planet Changing Today





Why Mars?



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• Mars: An Abode for Life?

- Mars is in the "habitable zone" with an early climate that had liquid water and sunlight on its surface, with basic elements to utilize
- If life originated there, does it still exist? If life did not originate there, why not?

• Mars: Comparative Study with Earth

- The climate of Mars has changed profoundly over time
- The record of that change is preserved in its surface morphology and composition. Mars was once wetter--and possibly warmer--with a much more active hydrological cycle

• Mars: A destination?

- Of all the planets, Mars is the most accessible
- Astronauts could walk on its surface by-mid century

Climate **Robots and Humans** History Sample Selection 3rd Wave of Space **Ancient Water** Validate Exploration? Paleo-Life DISCOVERY Resources Extant Life? ROBOTICS ROBOTICS ROBOTICS HUMANS ROBOTICS & HUM EXPLORATION **Deep Drilling** Field Studies Return Sample Sample Selection Site Selection Reconnaissance